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Effect of Carbonation on Concrete Strength: A Systematic Review

Nur Shafiqah Ramlee[1], Saddam Hussein Abo Sabah[1], Mohd Irwan Juki[2]*

[1]Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor, 86400, MALAYSIA

[2]Jamilus Research Centre, Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor, 86400, MALAYSIA

*Corresponding Author

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Abstract: Carbonation occurs in concrete as a result of carbon dioxide from the atmosphere penetrates the concrete body via the pores and reacts with calcium hydroxide forming calcium carbonate. The aims of this study is to observe the effect of carbonation on concrete properties and the relationship between carbonation depth and concrete compressive strength via the comparison of three selected articles. The comparison surpurisingly showed that the presence of carbon dioxide can enhance the compressive strength of concrete and reduce the pores. However, the amount of water in the presence of carbon dioxide reduces the compressive strength of concrete.

Keywords: Concrete, Carbonation, Compressive Strength

1 Introduction

Concrete is a common material for many construction applications, and its strength, durability, reflectivity, and flexibility make it widely utilized. These properties make it a long-lasting and sturdy option for many domestic and commercial settings. Concrete is famous for its high resistance. The degree of strength could be changed by altering the ratio of cement, water and aggregate to meet the needs of a particular project. Concrete amazingly strengthens year after year. This is because of the ability of the cement portion to form bonds with

**Corresponding author: irwan@uthm.edu.my*

surrounding moisture particles. Concrete is a strongly alkaline substance and the range of pH is 12.6 if uncarbonized. Carbonation occur on the surface of concrete and likely reach the steel reinforcement depth of the concrete. In most concrete structures, reinforcement bars are needed, because concrete have strong in compression but poor in tension strain

Concrete carbonation state as a mechanism of carbon dioxide that presence from the air penetrates into concrete by the pores. and reacts with calcium hdroxide and formation of calcium carbonate occur. When concrete comes into contact with carbon dioxide and other airborne contaminants, then there can be a reaction. With the water in the cement, carbon dioxide can form carbonic acid which then neutralizes the concrete's alkaline state. When this occurs, the carbonation moves as a front through the concrete which slowly decreased the pH value to 8; 7pH is neutral. Porosity and cement content are critical for the occurrence of carbonation in such a way that high porosity and low cement content accelerate the carbonation process.

2 Methodology of Study

2.1 Flowchart of Methodology

The flowchart below (Figure 1) depicts the followed methodology in the current study. The study is basically a simple systematic review that consists of several stages. The systematic review process led eventually to the selection of three articles which will be the main subject of this review paper. Figure 2 explains the whole process that was followed during the systematic review process.

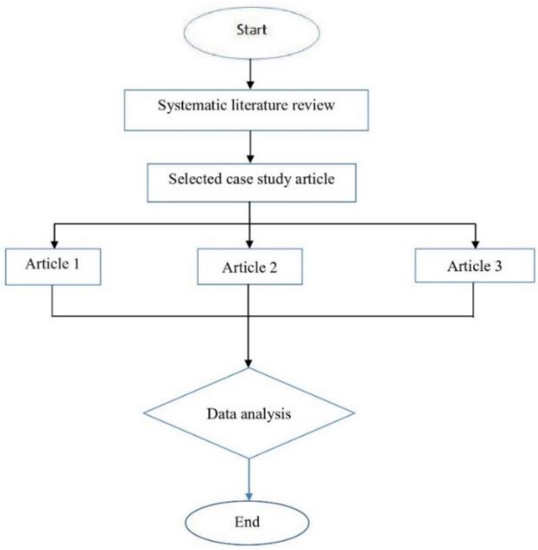


Figure 1: Flowchart of the study.

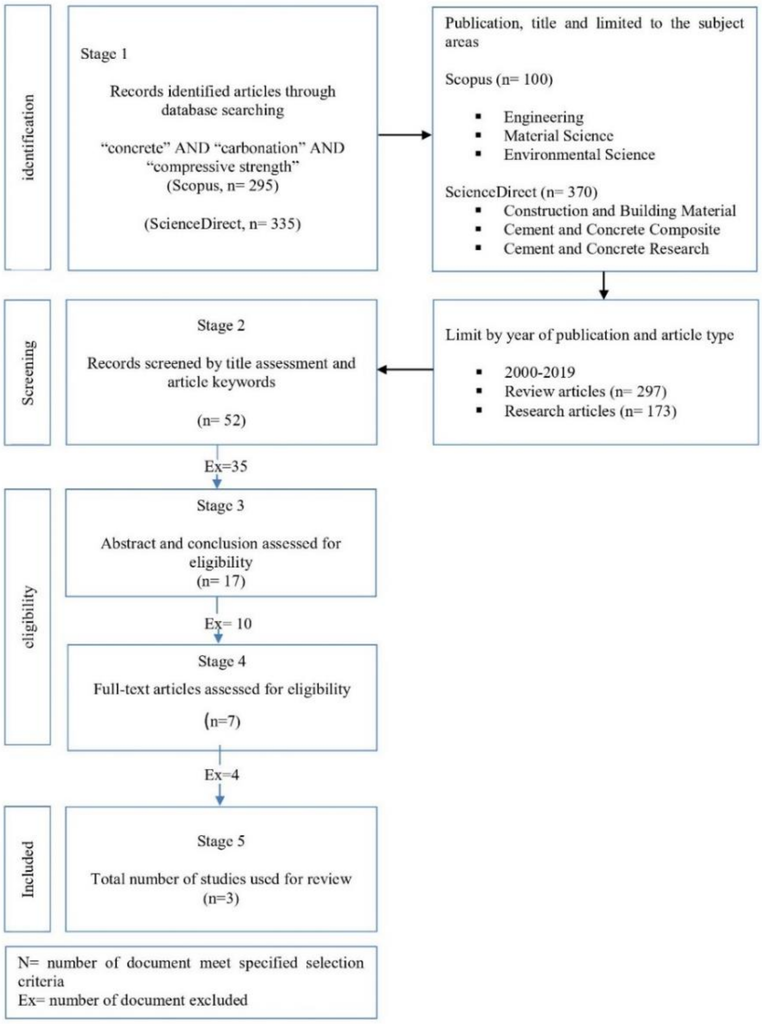


Figure 2: Systematic review process.

3 Results and Discussion

The data obtained for compressive strength had been analyzed and discussed. The results included the factors that influence the strength of the concrete such as carbon dioxide concentration and water ratio.

3.1 First Case Study

Chi et al. [1] carried out an experimental work to study theinfluence of carbonation on thecompressive strength of concrete and determine the relationship between the compressive strength and carbonation depth. Two groups of concrete mixtures (Ordinary Portland Concrete (OPC) with water ratio of 0.58 and 0.48 and self-compacting concrete with water ratio of 0.40 and 0.36) were used. The water/binder ratio was takenas water and superplasticizer weights divided by the weight of cement and slag. Specimens of concrete with size of 100 mm x 200 mm were cleaned from dust ans loose particles then sealed on the top and bottom surfaces. Three CO_2 concentration levels were chosen: 50, 75, and 100%. The specimens were tested at the age of 7,14, 21 and 28 days. Phenolphthalein solution was also utilized to measure the carbonation depth in the concrete specimens. The Phenolphthalein consisted of 70% of ethyl alcohol, and it was sprayed on the specimens surface. The Phenolphthalein solution is acolorless acid which turns into red when the pH is above 9.5 indicating that the specimen is corrosion-free. However, it remains colorless if carbonation takes place. Table 1 presents the concrete mix proportions for the two types of concrete used in chi et al. study [1].

Table 1: Mix proportion of concrete (kg/m^3) [1]

Mix No.	w/b	Cement	Water	Slag	Sand	Aggregate	Super-plasticizer	Slump(cm)
N58	58	350	203	0	735	1024	0	14
N48	48	424	203	0	768	945	0	13
S40	40	200	191	300	912	722	9.5	23.5
S36	36	400	177	125	924	732	12.0	25

Figure 3 shows that the carbonation depth increases with the increase of both curing time and CO_2 concentration for all mixtures. The carbonation depth was determined to be higher for specimens with higher w/b ratios and that was due to the pore system in the hadrdened specimens. Similar results were found by Nagla and Page [2].

Figure 3 also shows that the addition of furnace slag reduced the carbonation depth because of the pozzolanic reaction occurrence which helped filling the pores within the spciemns. Nevertheless, curing time was found to be the most critical factor that affected the carbonation rate and this finding was supported by the study of Roy et al [3].

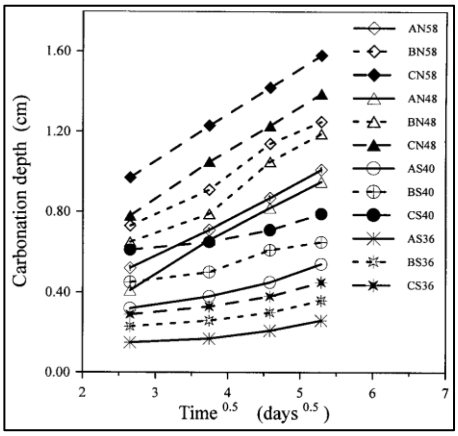
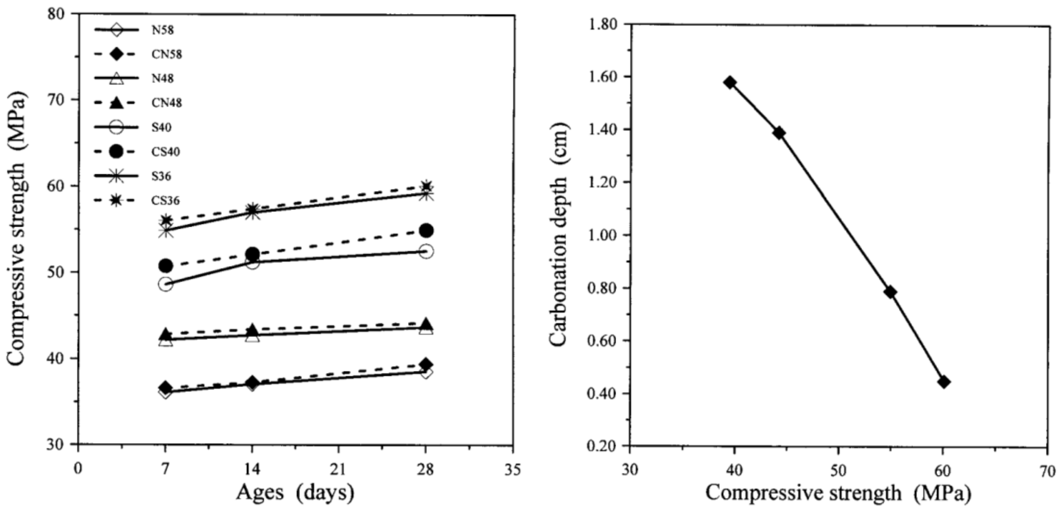


Figure 3: Carbonation depth for different mixes [1].

The compressive strength results at 7, 14, and 28 days are displayed in Figure 4a. The compressive strength increased slightly for the carnonated specimens due $CaCO_3$ which filled the pores. indicates that the compressive strength of the carbonated concrete is increases relative to non-carbonated concrete. In Figure 4b, the relationship between the carbonation depth and the compressive strength at 28 days for specimens with 100% CO_2 concentration shows that the carbonation depth decreased as the compressive strength increased. According to Wierig [4] and Fattuhi [5], this relationship is also affected by the cement type and curing period.



(a) (b)

Figure 4: (a) Effect of curing period on compressive strength (b) relationship between carbonation and compressive strength.

3.2 Second Case Study

In 2008, Kim et al. [6] conducted an experimental study to analyze the effect of carbonation on the rebound number and compressive strength of concrete. Three types of concrete mixtures were adopted: a low strength (LS) mix, a medium strength (MS) mix, and high strength (HS) mix. Table 2.

For the carbonation depth test, two prism specimens of size (100 mm x 100 mm x 400 mm) were prepared while 24 cylindrical specimens of size (⌀ 100 x 200 mm) were prepared for the compressive strength test. After a day of casting, all the specimens were dismantled and put in lime-saturated water for a month. Subsequently, half the specimens were cured in natural air condition while the other half were cured in accelerated carbonation chamber with CO_2 concentration of 5% of the weight obtained after 4 months. The relative humidity for both was retained at the same constant value (70 ± 5 %) for each curing condition to avoid potential errors due to differences in the humidity.

Table 2: Concrete mix Proportions [6].

Strength level	w/c	Unit weight (kg/m^3)						Ad. (%)
		W	C	S	g	s/(s+g)	Air (%)	
LS	0.68	180	265	887	993	0.47	1.5	0.0
MS	0.46	180	391	785	991	0.44	1.51	0.8
HS	0.28	180	643	567	1000	0.36	1.5	2.0

Based on Figure 5, the carbonation depth is almost zero for high strength concrete. However, the highest rate of carbonation depth was observed in low strength concrete.

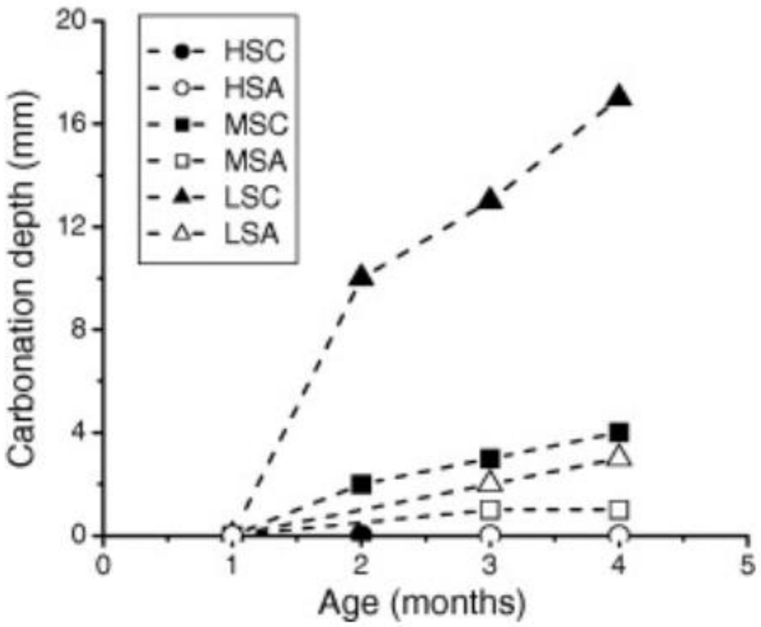


Figure 6: measurement of carbonation depth [6].

The absolute and normalized values of compressive strength is shown in Figure 7. The compressive strength of the concrete in the accelerated carbonation chamber was much higher than that of the concrete cured in normal air. However, the additional increase of strength was negligible since carbonated area is small compared to the total area of cylinder specimen, except for the low strength concrete. It can therefore be concluded that the compressive strength of the specimen is hardly changed by carbonation because it affects only the near-surface region of concrete.

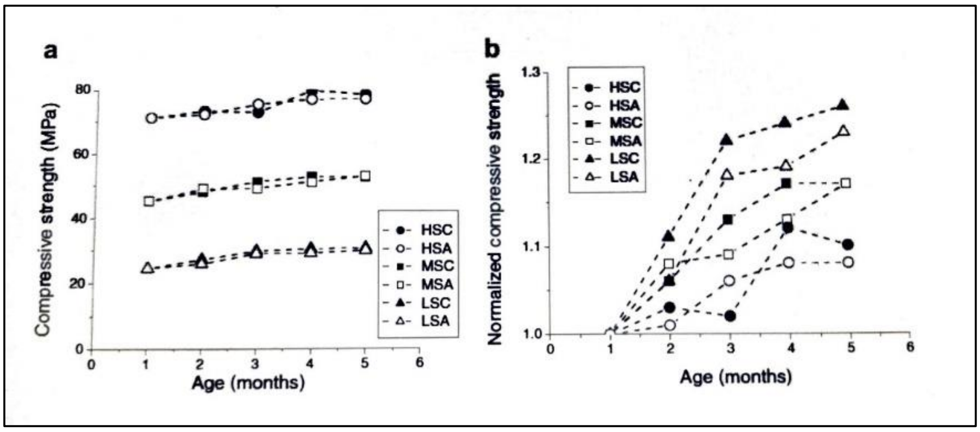


Figure 7: Measured compressive strength: (a) absolute value and (b) normalized value [6].

3.3 Third Case Study

The third study was conducted by Ahmed and Benharzallah [7]. The study evaluated the effect of the carbonation and the cement (limestone cement (CEM II) and ordinary Portland cement (CEM I)) on the ductility and compressive strength of concrete.

The OPC (CEM I) had a density of 3.07 g/cm^2 while the limestone cement (CEM II) density was 3.0 g/cm^2. Cubic specimens of 10 x 10 x 10 cm^3 were prepared and put in a carbonation chamber containing a mixture of 50% air and 50% CO_2 at 65% relative humidity and 20^{o}C temperature. The samples were then removed from the carbonation chamber at 7, 14 and 28 days and weighed to measure the evolution of the accelerated carbonation. In order to determine the carbonated concrete depth, the samples were sliced into two parts and sprayed with phenolphthalein solution to measure carbonation depth. Four specimens were tested ; three for the measurement of the concrete carbonation depth, and one was used as a control for the evaluation of the mass.

Table 3 summarizes the results of the compressive strength of the control and carbonated samples as a function of the duration of exposure to CO_2 for CEM I and CEM II.

Table 3: Compressive strength of control and carbonated samples [7].

Age	Compressive strength (MPa)			
	CEM I		CEM II	
	Control Sample	Carbonated Sample	Control sample	Carbonated sample
7	42.29	45.20	38.34	40.81
14	43.47	45.57	41.08	42.90
28	49.67	52.14	42.78	46.00

According to Figure 8, the compressive strength increased for the carbonated sample with the increase of the curing period. Compared to the compressive strength of the control specimen, the strength increased by 7, 13, and 10 % at 7, 14, and 28 days, respectively. This indicates that the carbonation blocked the pores by creating calcite which contributed to the enhancement of the compressive strength.

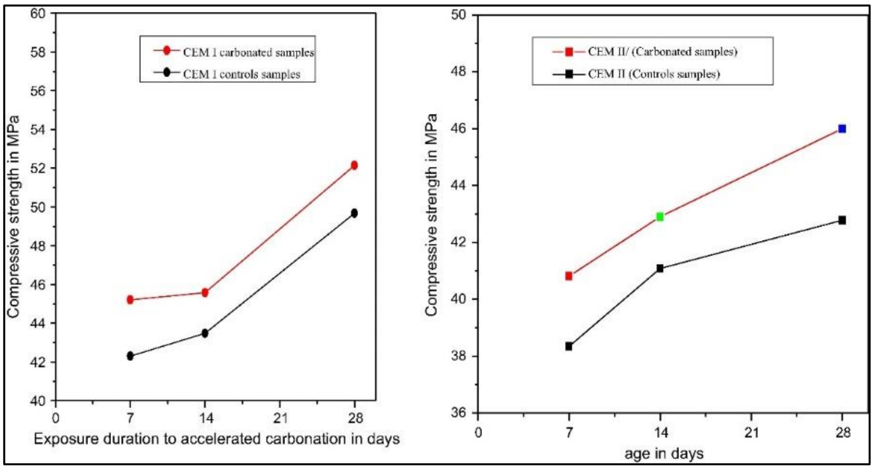


Figure 8: Evolution of compressive strength (for carbonated and control concrete samples: CEM I and CEM II) [7].

3.4 Comparison of the compressive strength due to carbonation on concrete for the studied articles

The comparison is going to be based on the compressive strength for the same value of CO_2 concentration, relative humidity, and curing duration.

Table 4 shows that the compressive strength results in [7] are the lowest (42.78 MPa) for the non-carbonated concrete; however, it increased slightly for the carbonated concrete. For the non-carbonated concrete, the results of [6] were the highest with 75MPa. For the carbonated concrete, the highest increase was obtained by [6] with 80 MPa and followed by Jack et al. [1] with 60 MPa.

Table 4: Comparison of compressive strength for all articles

	Jack et al. [1]		Kim et al. [6]		Ahmed and Benharzallah [7]	
Relative humidity	Carbonated	Non-carbonated	Carbonated	Non-carbonated	Carbonated	Non-carbonated
(70±5)%	60 MPa	55 MPa	80 MPa	75 MPa	46 MPa	42.78 MPa

4 Conclusion

The compressive strength of carbonated concrete from three selected articles have been discussed in this paper. The results showed that the presence of carbon dioxide in concrete enhances the compressive strength and reduces the porosity of the concrete. It was also noticed that the amount of water in the presence of carbon dioxide has a negative impact on the compressive strength of concrete. For future research, it is significant to conduct an experimental study using different grades of concrete mixes and longer curing durations to fully capture the behavior of carbonation.

Acknowledgement

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